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AN ICE STRENGTH INDEXER FOR MODEL TOWING TANKS

- Summary Report -

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17. Abstract

The mechanical properties of model ice are usually determined by manual cantilever beam tests. Additional ice property calibration is not feasible with existing testing equipment because model ice properties change with time. This report describes the design, development and preliminary testing of an instrument, the Indexer, which monitors the primary mechanical properties of the model ice, simultaneously with model tests. The Indexer uses three instrumented plates to monitor the flexural, shearing and crushing strength of the model ice.

The model tests were conducted at the National Research Centre Hydraulics Laboratory in Ottawa, Canada. The results indicate that the Indexer is capable of monitoring the three ice fracturing mechanisms and that the device will be of significant benefit to model ice testing tanks.

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17. Résumé

Les caracteristiques mécaniques de la glace sont généralement mesurées par la methode de la poutre. Toutefois, ce matériel d'essai ne permet pas de proceder à d'autres déterminations, étant donné que les caracteristiques d'une glace ne sont pas stables dans le temps. La recherche dont il est rendu compte ici concerne l'étude, la mise au point et les premiers essais d'un dispositif appelé "Indexer" capable de mesurer en continu les principales caracteristiques mécaniques d'une glace modèle en même temps que se deroulent les essais sur modèle réduit dans un bassin de carènes. Pour cela, l'Indexer comporte trois plaques dotées d'instruments permettant de mesurer la résistance de la glace à la rupture en flexion, cisaillement et écrasement.

Les essais du dispositif ont eu lieu dans le Laboratoire d'Hydraulique du Conseil National de Recherches à Ottawa. Ces essais ont montré que l'Indexer est capable de mesurer les efforts exercés dans les trois axes de rupture et qu'il promet de faire avancer la recherche dans le domaine des essais sur modèle réduit dans des bassins de glace.

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1. INTRODUCTION

During the last three years, Melville Shipping Ltd. (Melville) has been actively involved in an extensive series of model ice tests on an existing icebreaking cargo ship. The tests were conducted in three of the major ice tanks in Europe and North America with simulated ice thicknesses of up to 2.2 m.

One aspect of the test programme was to review the procedures adopted by each tank to monitor the model ice characteristics. Although the methods used in each tank were different, in general it was concluded that:

- The present methods for measuring model ice properties are difficult and time consuming.
- Usually only the flexural strength and elastic modulus were measured, which make it difficult to compare results from different tanks using different types of model ice.
- Considering some of the scaling problems associated with model ice, it would be appropriate to measure other properties such as the compressive and shear strength.

Responding to these conclusions, Melville has developed a device called an Indexer. The objective of the Indexer is to monitor the mechanical properties of the ice continuously along the length of the tank simultaneously with the ship model test.

This report describes the initial design and model testing of the Indexer at the National Research Council (NRC) Hydraulics Laboratory and presents the preliminary correlation between the Indexer output and manual ice strength measurements.

2. INDEXER: DESIGN AND CONSTRUCTION

The design criteria for the Indexer were;

- The Indexer must be capable of monitoring the mechanical properties of the model ice continuously, over the entire ice sheet, simultaneously with the model test.
- The Indexer should not influence the model test.
- The Indexer must be simple to deploy requiring minimal maintenance.
- The configuration of the prototype should be flexible to permit as many adjustments as possible during the design development.

From the preliminary design stage it was recognized that it would not be possible to develop a simple device that could measure mechanical properties directly comparable with model or full scale ice. The information gathered would be an "index" of the ice sheet properties and would have to be correlated with conventional techniques. Once the correlation was established, the conventional techniques would only be used to monitor the ice during the growing and tempering stages and possibly after the model test for checking and re-calibration purposes.

Three mechanical properties were targeted for monitoring by the Indexer; flexural strength, shear strength and crushing strength. The device was designed using flat plates orientated so that they would fail the ice predominantly in these three modes. The forces necessary to produce these breaking mechanisms could then be recorded continuously and would represent the ice sheet strength.

A schematic of the Indexer is shown in Figure 2.1. The motors on the forward frame cut parallel lines in the model ice directly in front of three instrumented plates which load the ice in either bending, shearing or compression. The bending plate is located directly behind and between the two cutters, inclined in the vertical plane, and is intended to fail the ice in a predominantly flexural mode. The shear plate, located adjacent to the bending plate, is also inclined in the vertical plane with one edge behind a cutter and is intended to fail the ice in a predominantly shear mode. The crushing plate is oriented vertically behind, and to the side of, the bending plate and is intended to fail the ice in a predominently crushing mode.

Considerable time and effort was invested in the initial configuration of the Indexer. Particular aspects of the design which are considered to be important are:

- The Indexer is constructed of 1/2 inch (12.7 mm) and 3/8 inch (9.5 mm) mild steel plate to obtain a high natural frequency (about 60 Hz).

- The ice cutters are high speed phneumatic drills which are capable of cutting 40 mm ice at 0.5 m/sec. The cutters have left hand screws to direct tailings and any entrained water down. This prevents wetting the ice surface which may influence the test results.

- The drills are mounted on a separate frame from the instrumented plates to minimise vibration effects.

- The plates are hinged to the main assembly using stainless steel machined bushings and pins to minimise corrosion effects and plate movement.

- The plates are instrumented using axial 'S' type water proof load cells, rated at 50 lb (222 N) for the bending and shear plates and 250 lb. (1,112 N) for the crushing plate.

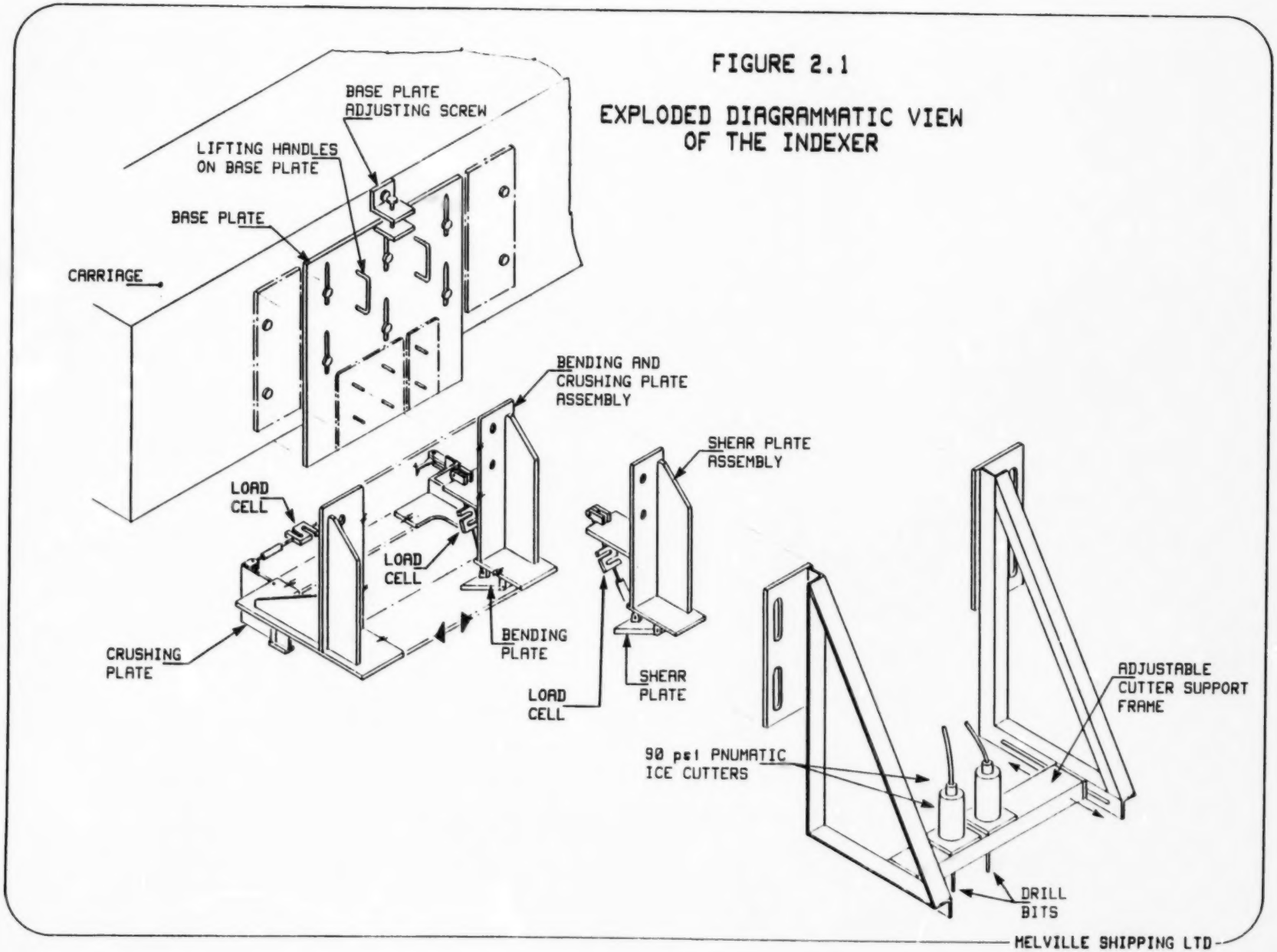


FIGURE 2.1

EXPLODED DIAGRAMMATIC VIEW
OF THE INDEXER

- The plates may be fitted with different surfaces to monitor the effect of friction.

- The plates are adjustable through a range of angles.

- The Indexer may be adjusted longitudinally, to change the plates relative position to the cutters, and vertically, to move the Indexer relative to the ice surface.

- The shear and bending plates are mounted separately to allow relative adjustment in the longitudinal direction.

- The Indexer is built in a number of sections which are easy to handle and move from one location to another.

3. MODEL TESTS

The model tests were conducted from December 1985 to February 1986 and consisted of five ice sheets at the NRC's hydraulics ice tank in Ottawa, Ontario. Table 3.1 presents the test programme and illustrates the range of ice conditions, speeds and Indexer configurations that were tested.

During the tests ice thickness was recorded every half meter along the track left by the Indexer. The flexural strength was recorded by cantilevers about 3 m from the Indexer track (to prevent the Indexer from influencing the cantilevers) and every 0.5 or 1 m down the tank depending on the test. Each cantilever location consisted of three beams tested manually with a calibrated spring loaded gauge.

Manual crushing and shearing tests have not yet been conducted to correlate those force outputs with the measured ice sheet strengths.

The main objective of the preliminary test series was to ensure qualitatively that the Indexer would fail the ice consistently with minimal influence on the surrounding ice cover. This objective was achieved. Minor disturbances of the ice sheet did occur on the crushing side of the Indexer, but are not considered significant.

Figure 3.1 presents typical load time histories obtained from the flexure, shearing and crushing plate instrumentation. In general each of the time series is consistent with the breaking mode of the ice.

- Bending Plate, Figure 3.1a. The load output from the bending plate is typical of the failure which would be obtained from a conventional cantilever beam test. In this case the load increases until there is an abrupt failure of the cantilever beam with the load dropping quickly. This cycle is then continuously repeated as the Indexer moves through the ice. Between the peaks, however, there appears to be a high

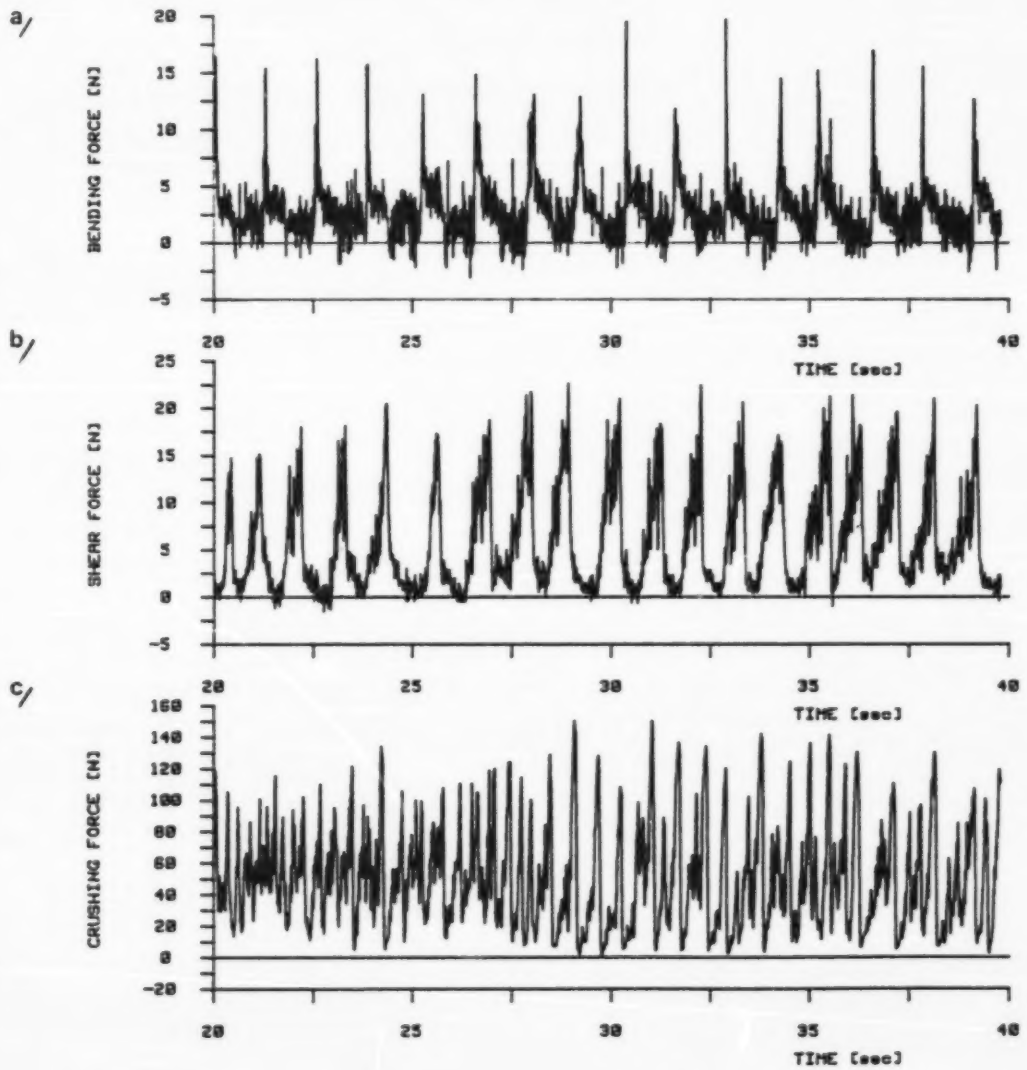
TABLE 3.1

SUMMARY OF TEST PROGRAMME

Test #	Ice Sheet #	Indexer Speed cm/sec	Ice Thickness [mm]	Ice Strength [kPa]	Comments
1	1	2.0	35	40	- December 17, 1985
2	1	5.0	35	40	- Nominal strength values recorded
3	1	20.0	35	40	
4	1	50.0	35	40	
5	1	1.2	35	40	
6	2	10.0	32 - 36	35 - 42	- December 19, 1985 - Single run over length of tank
		- Indexer Modified -			
7	3	10.0	35 - 38	26 - 38	- February 13, 1986 - Cutters in forward position - Indexer in low position
8	3	10.0	36 - 40	32 - 42	- February 13, 1986 - Cutters in aft position - Indexer in low position
9	4	10.0	37 - 43	24 - 35	- February 18, 1986 - Cutters in aft position - Indexer in high position
10	4	10.0	37 - 42	32 - 41	- February 18, 1986 - Cutters in aft position - Indexer in low position
11	5	10.0	38 - 42	29 - 48	- February 20, 1986 - Cutters in aft position - Indexer in high position
12	5	10.0	36 - 43	5 - 7	- February 20, 1986 - Cutters in aft position - Indexer in high position

FIGURE 3.1

TYPICAL TIME HISTORIES OBTAINED
FROM THE INDEXER



INDEXER SPEED 10 cm/sec
ICE STRENGTH 35-42 kPa
ICE THICKNESS 32-36 mm

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frequency cyclic loading. The reason for this is not clear, but could be associated with the buoyancy forces of the broken beam on the plate. More work is required to identify the source of this load.

- Shearing Plate, Figure 3.1b. The load output from the shearing plate is difficult to interpret unambiguously since the shearing action of the plate includes a component of flexural failure in the form of a series of load peaks. It is anticipated that this will be modified in the next phase of ice tests at the Institute for Marine Dynamics (IMD) by decreasing the width of the shear plate to reduce the bending component in the failure process.

- Crushing Plate, Figure 3.1c. The output from the crushing plate is cyclic at a much higher frequency than either the bending or shear plate output. This represents crushing and the elastic buckling of the ice as the Indexer moves through During the tests, the latter failures can be seen in the ...m of waves radiating away from the Indexer. To prevent them from influencing the model being tested, the crushing plate must be directed away from the model being tested.

Having established the good qualitative behaviour of the Indexer, a procedure must be developed that will permit the correlation between the Indexer load cell outputs and the measured strength of the ice sheet. Although this is a major task, the limited results of these preliminary tests indicate that it will be possible. The only mechanical property measured during the tests was the flexural strength. Figure 3.2 illustrates the procedure used to deduce the "index" of flexural strength from a typical load output. Figure 3.3 presents the typical correlation that was achieved between the Indexer and the measured ice strength using manual cantilever beam techniques. In general, the correlation is good and demonstrates the capability of the technique. It is important to note that the "absolute" values of flexural strength, calculated from the Indexer output, will not be identical to the manual values because of the different type of loading technique. The trends of increasing/decreasing ice strength are important and this is illustrated in Figures 3.3.

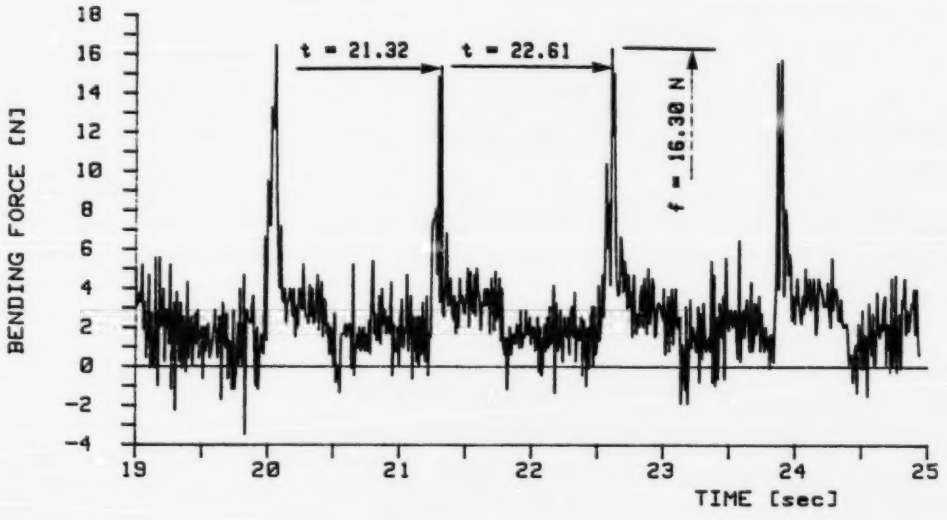
4. APPLICATION OF THE INDEXER TO MODEL TESTS

The Indexer has been developed to improve the performance prediction of icebreakers from model ice tanks. This will be accomplished by obtaining more information on the ice in which the model is being tested. The initial model tests indicate that the Indexer will be capable of characterising the model ice in terms of the flexural, shear and crushing strength.

Once these values have been established for an ice sheet, their influence on the resistance of the model icebreaker must be determined. In

FIGURE 3.2

PROCEDURE USED TO DEDUCE INDEX OF FLEXURAL STRENGTH



- FORCE VS TIME DATA

Vertical Force Recorded at 22.61 Seconds, F	=	16.30 N
Angle of Load Cell to Vertical	=	22.5^{o}
Vertical Component of Force, F	=	F x (cos 22.5)
	=	15.06 N

- FROM POSITION VS TIME DATA

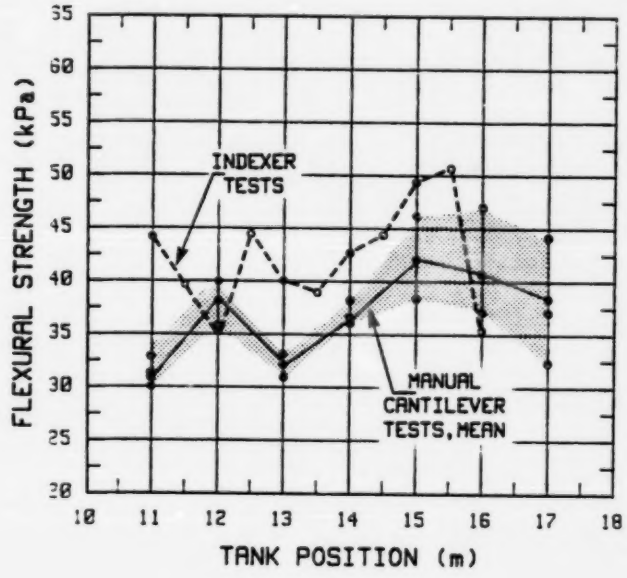
Location of Indexer at 22.61 sec	=	6 m
Ice Thickness at 6 m, t	=	3.3 cm

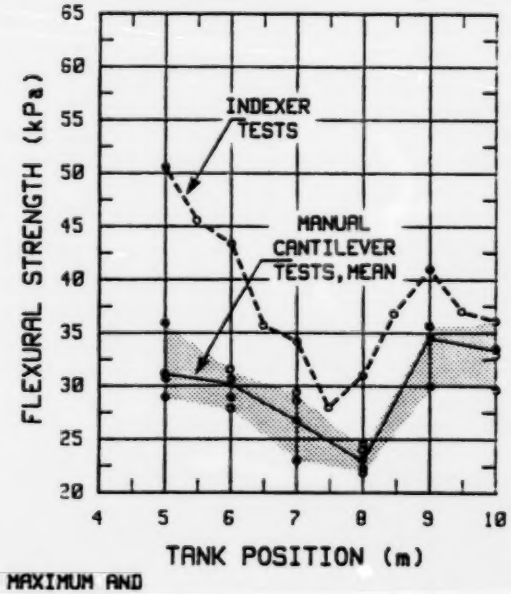
- FROM SPEED VS TIME DATA

Speed of Indexer	=	10 cm/sec
Time Span Over Cantilever Fracture	=	1:29 sec
Length of Cantilever, L	=	12.9 cm
Width of Cantilever, W	=	18 cm
Bending Stress at Failure	=	$\frac{6 \times F \times L}{W \times t^2}$
	=	59 kPa

FIGURE 3.3

TYPICAL CORRELATION BETWEEN MANUAL CANTILEVER TEST RESULTS AND INDEXER TEST RESULTS





RANGE BETWEEN MAXIMUM AND MINIMUM CANTILEVER TEST

O RECORDED DATA POINTS

● MEAN OF DATA POINTS

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order to accomplish this it is necessary to establish the tendancy for the model hull to fail the ice in flexure, crushing or shearing. This can be accomplished by mathematically defining the subject hull form and icebreaking action in terms of hull form coefficients.

The mathematical definition of the hull form will be developed from existing work, conducted over the last decade, on the analytical prediction of hull performance. The important difference between the existing mathematical relationships and the form coefficients that will be developed for the Indexer, is that the Indexer constants will focus on the tendancy for a bow to break ice in a particular fashion and will not attempt to predict the actual resistance of the hull.

This approach avoids the criticism, often leveled against predicter equations, that it is impossible to duplicate the irregular icebreaking mechanism occurring at the ship's bow using mathematical formulations. The Indexer hull form definition will only have to be sensitive to trends and will not represent absolute values.

The final form of the relationships will depend on the analysis but it may be envisaged that three coefficients, or relationships, will be developed that represent the bending, crushing and shearing components of the icebreaking resistance.

5. CONCLUSIONS

The primary objective of this project has been to develop a device that can characterise the mechanical properties of model ice. The device that has been developed, referred to as the Indexer, uses inclined plates to fracture the ice in flexure, shearing and compression, and monitors the loads associated with each of these failure mechanisms.

The following conclusions may be made:

- The initial series of tests in ice sheet one indicate that there is little or no speed dependancy associated with the ice failure mechanism. Insufficient tests were conducted to establish any relationship between load output from the Indexer and speed, for identical ice sheets. As a result the strain rate dependancy of the load output from the Indexer was not investigated.

- Limited correlation has been possible between the Indexer and the manually recorded strength measurements. This is considered to be due partly to the variation of ice strength and thickness recorded along the length of the tank, and the implied variation across the width.

- The bending plate fractures the ice in almost pure flexure yielding a fracture signature very similar to the load/time curves recorded from cantilever beam tests.

- The shearing plate fractures the ice in a combined shearing bending failure. The preliminary tests indicate that the shearing plate is sensitive to ice thickness.

- The crushing plate fractures the ice in a combined crushing and shearing action.

- The bending and shearing plate are sensitive to the position of the ice cutter. From preliminary tests the best position for the ice cutters was close to the bending and shearing plates.

- The bending and shearing plates were not found to be very sensitive to the vertical position of the Indexer. However, considering the icebreaking action, this aspect should be investigated in more detail.

- A significant variation in crushing strength was identified with the Indexer during one test. The conventional manual tests were not sensitive to the variation.

- The influence of the ice elastic modulus has not been investigated.

6. RECOMMENDATIONS

The success of the preliminary model tests on the Indexer result in a number of recommendations.

- Additional model tests must be conducted to improve the correlation between the Indexer load outputs and the conventional ice strength test procedures.

- The additional tests should focus on correlating the shear and crushing plate load outputs to these properties of the model ice.

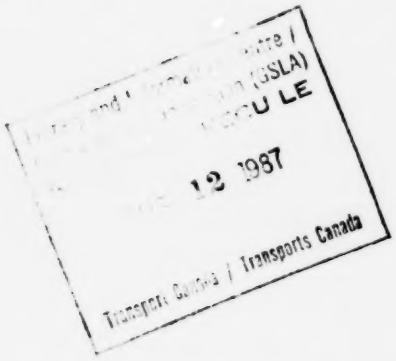
- The influence of the elastic modulus on the form of the failure mechanism recorded by the Indexer should be investigated.

- The sensitivity of the load outputs from the Indexer to its vertical position should be investigated further.

- The hull form coefficients should be developed that will be used to evaluate a particular icebreaker bow's tendancy to fracture the ice in bending shearing and crushing.

- The procedure to correlate the hull form coefficients, ice strength recorded by the Indexer and total icebreaker model resistance should be developed.

- Based on the success of the Indexer it is recommended that the design is kept confidential until the full potential of the device becomes known. This will permit the Melville/IMD project team to market the device to offshore ice tanks that may wish to adopt the device, thus providing some return to IMD for their contribution to the project.



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